Developing a Solid-State Circulator to Provide Receiver Isolation at 300 MHz for *in vivo* Electron Paramagnetic Resonance

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Background and Introduction

Electron Paramagnetic Resonance (EPR) imaging technology enables *in vivo* functional imaging in small animal models. This imaging modality uses non-toxic free radical probes to obtain 3D maps of tissue oxygenation quantitatively and non-invasively with high spatial and temporal resolution. EPR imaging has been successfully implemented with mouse models of human cancer to obtain information regarding the dynamics of tumor physiology and hypoxia, factors that are critical for treatment selection (whether it be chemotherapy, antiangiogenic drug therapy, or radiotherapy) and response monitoring. The capabilities of EPR imaging have been found to be very useful in screening anti-cancer agents, as well as understanding their mechanisms of action. Anatomically co-registering quantitative maps of oxygen distribution in tumors should play a vital role regarding prognostic value, as well as in developing appropriate tumor treatment strategies. Other techniques, which provide such information, are either invasive or not quantitative. Given the requirements of RBB research, there is no commercially available EPR imaging system with sufficient features, capabilities, and performance, therefore providing the motivation for this longstanding in-house development.

EPR vs. MRI

EPR	MRI
Can only detect relaxation of unpaired electrons (free radicals)	Detects relaxation of protons in ^{1}H nuclei
Electron relaxation times up to ~10 µs	Proton relaxation times up to ~5 s
B_0 Field Strength = 10.37 mT (@300 MHz)	B_0 Field Strength = 7 T (@300 MHz)

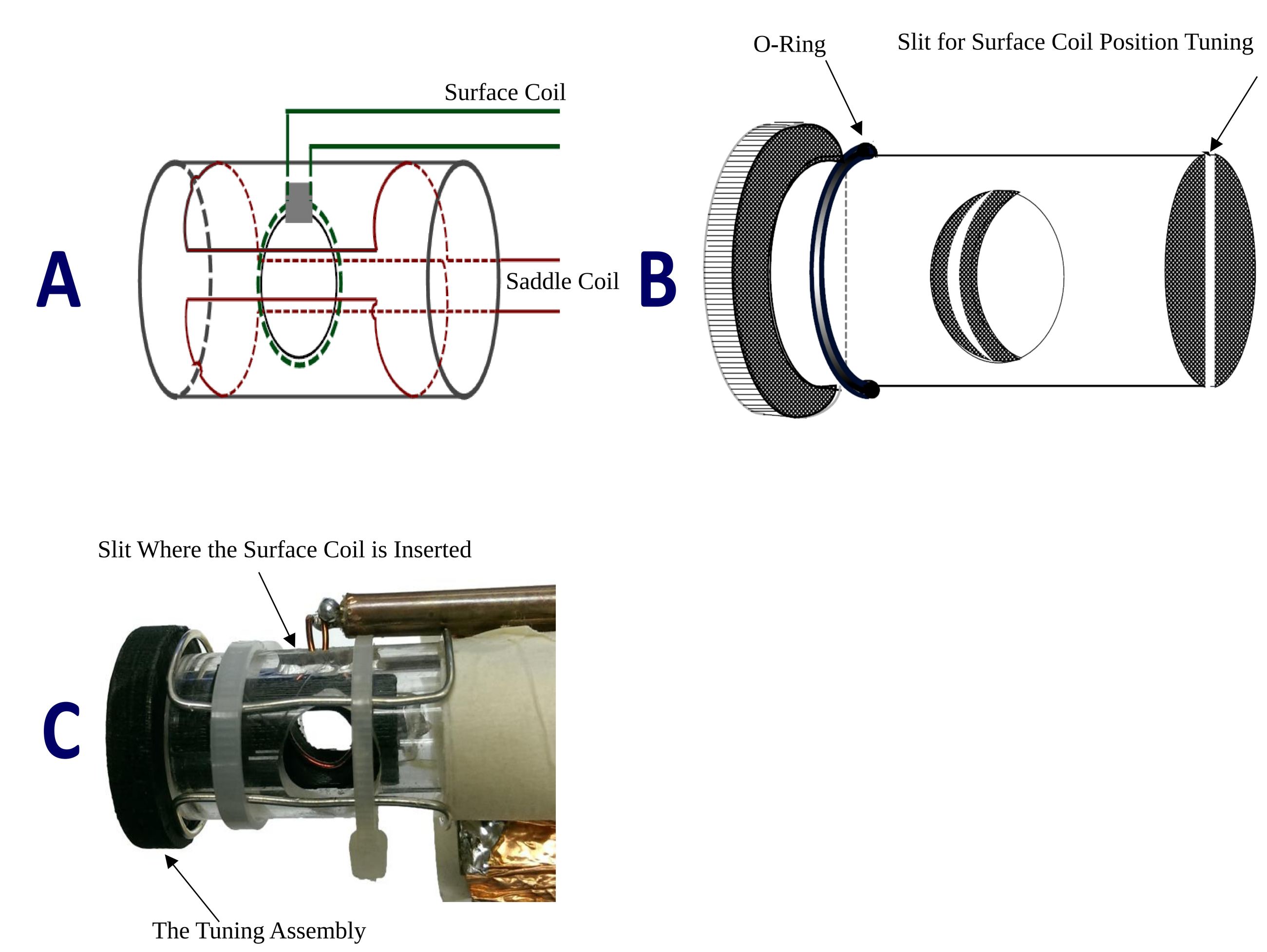
EPR Challenges

Short relaxation times
- Requires high speed data acquisition
- Requires a short resonator recovery time
- Back projection image reconstruction is the only option

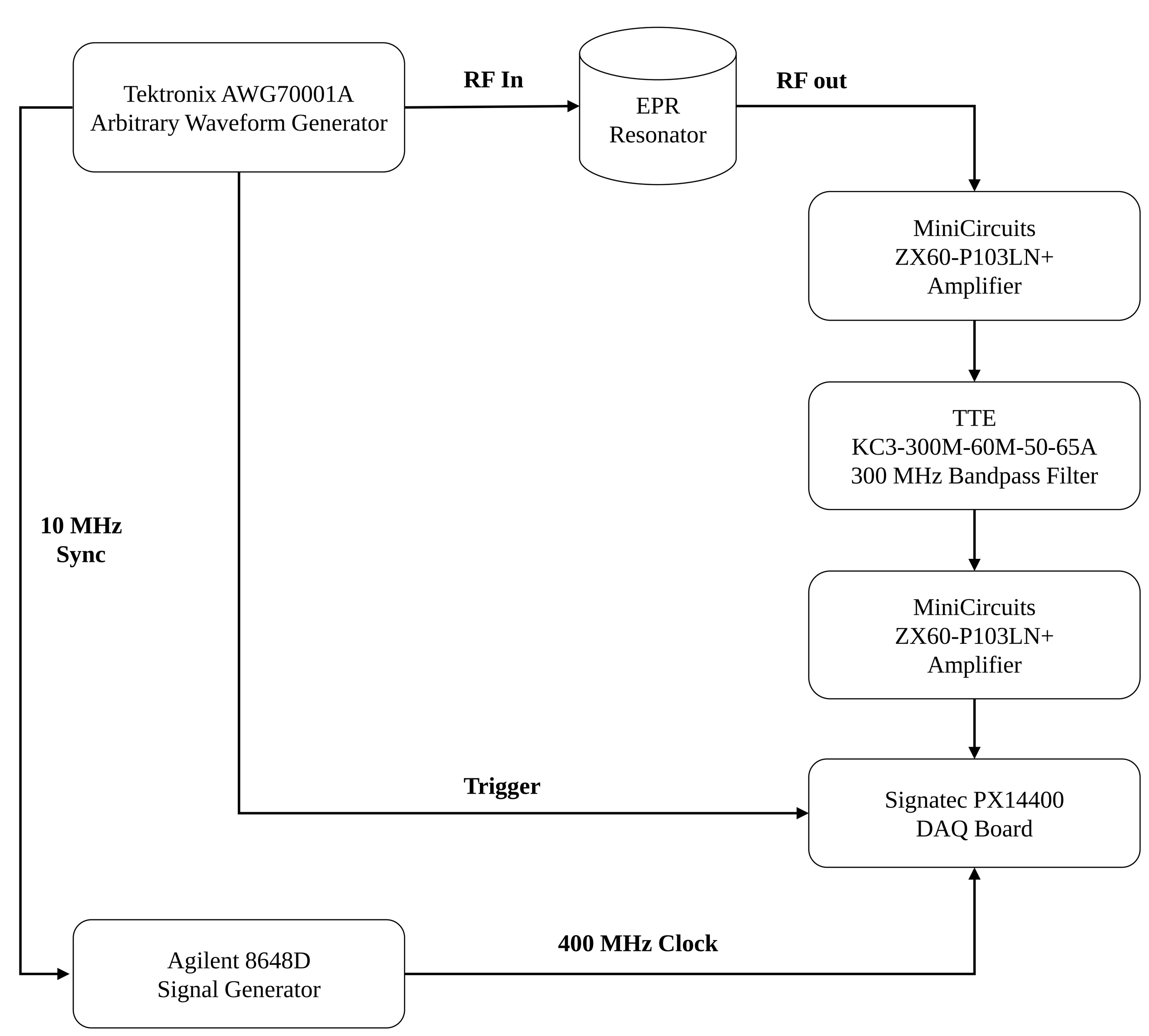
Low B_0 field strength
- Results in a noisier environment
- Resonant frequency is still high enough that tissue heating is a concern if the technology is scaled up for human use

Lower Received Signal Levels
- Require very sensitive detectors
- Utilize techniques to improve signal-to-noise (i.e. averaging and stochastic correlation sequences)

Current System



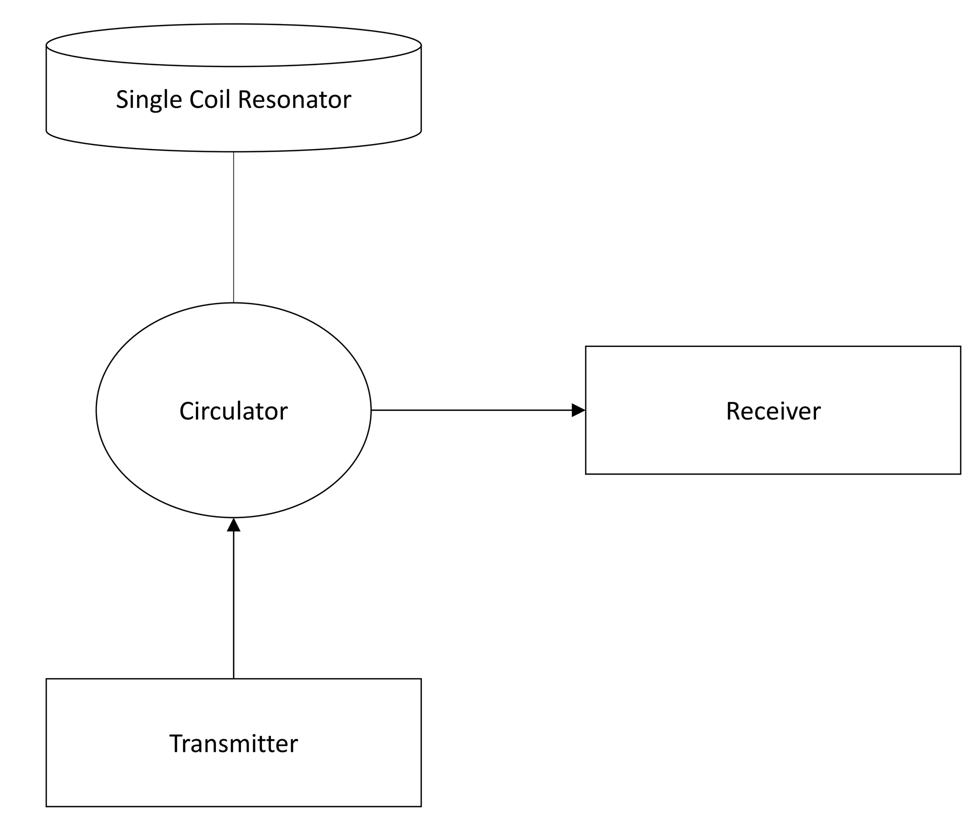
(A) Schematic of a crossed resonator with saddle transmit and an inner surface coil receive pair. (B) The tuning assembly. The mechanism is of a PVC insert fabricated with a slit in the middle. The diameter of the insert is the inner diameter of the Lucite tube. The slit width is equal to the diameter of the surface coil wire. In the assembly, an O-ring is positioned in such a way, once the tuning assembly is inserted, it will hold tightly. Since the surface coil is inside the slit, the position can be changed by tuning the assembly. (C) The actual resonator assembly.

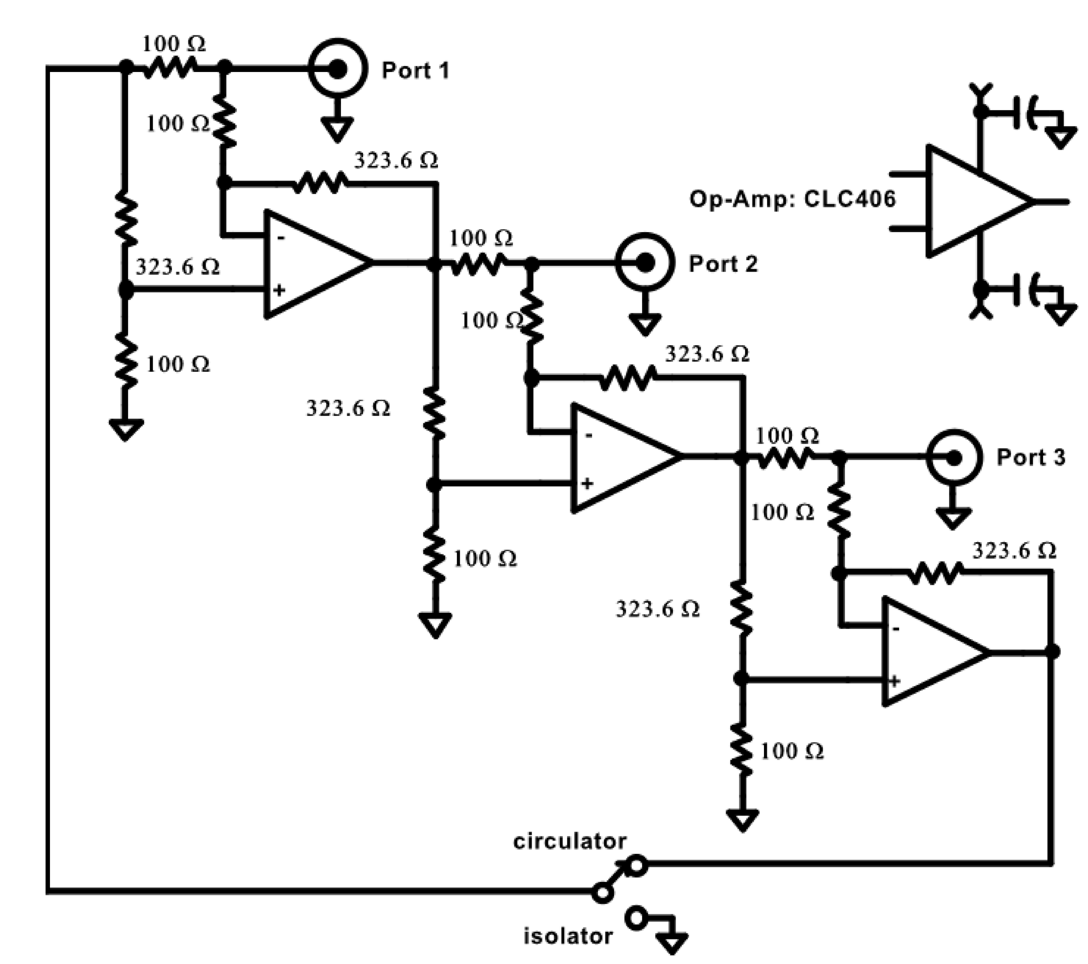


Block diagram of EPR system. In this experimental setup, a Tektronix AWG70001 arbitrary waveform generation is the RF excitation source. An Agilent 8648D is synchronized with the AWG to provide a synchronized clock to the Signatec PX14400 data acquisition board. The RF excitation is input into a custom in-house EPR cross-coil resonator. The RF response from the resonator is amplified and filtered before being acquired by the data acquisition board.

Proposed System

Replace the dual coil system with a single coil and use a solid state circulator to provide the necessary isolation between the transmitter and receiver.





Circulator Circuit Design Schematic

A circulator is a 3-port device used to isolate signals between ports. Signal input into a port will output at the next port in a clockwise direction but not at the third port. With plans to use a low-power EPR system to image small animals, the circulator is needed to provide isolation, since animal movement within a dual-coil system will greatly affect the isolation between the coils. At the operating frequency of 300 MHz, standard circulators do not provide enough bandwidth for imaging applications. Developing a solid-state circulator will achieve the bandwidth that is required for imaging.

Conclusion

Currently, the circuit is still in the early stages of development. The major issues being diagnosed is trying to find the common mode rejection of the op amp. This requires fine tuning of the balance of resistance between the inverting and non-inverting inputs of the op amp. Once this is resolved, the circulator can be developed by simply multiplying the test circuit and putting them in series.